# EMMA Lattice Configurations

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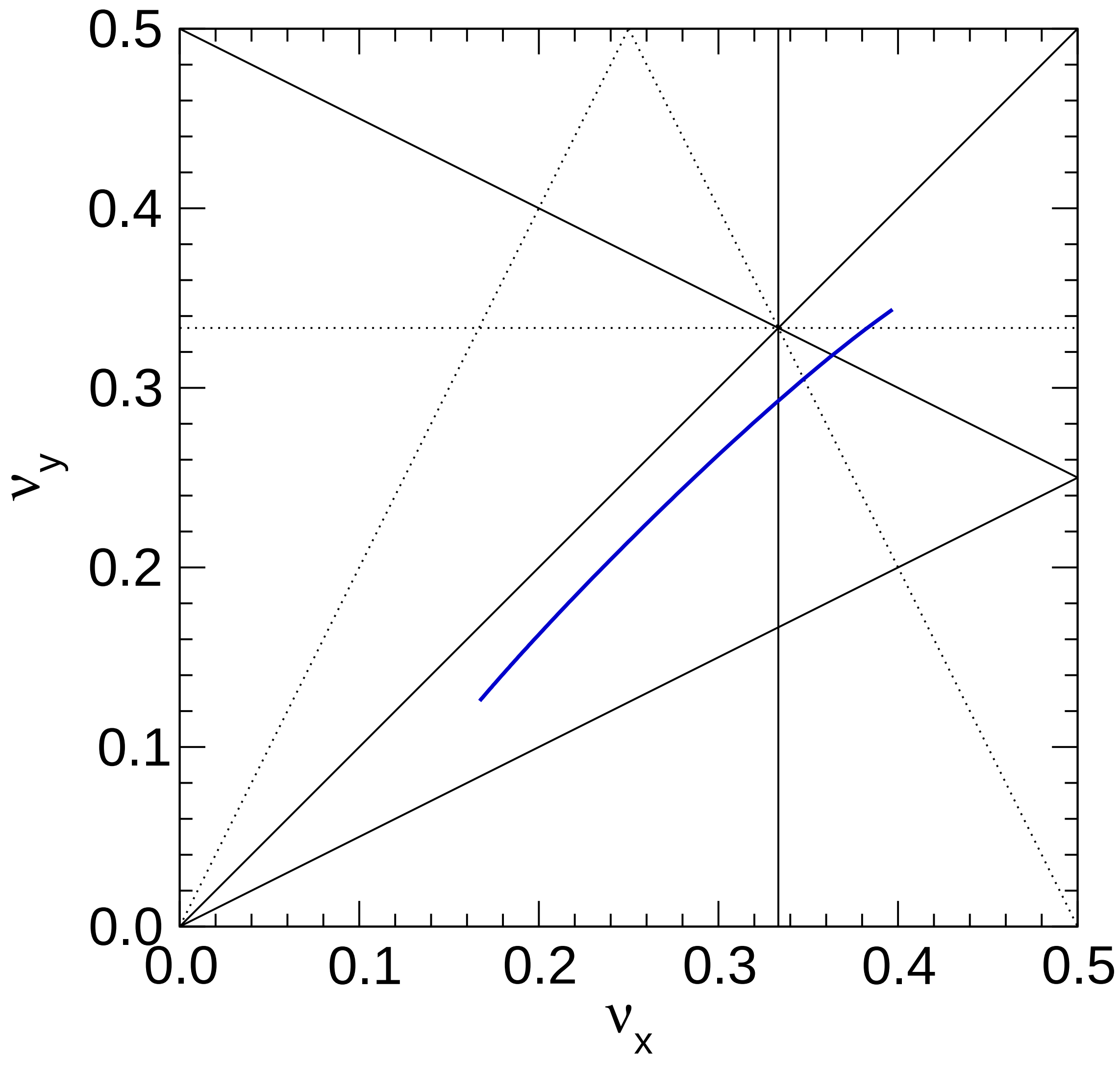
# Baseline Lattice

- Based on desired behavior in the tune plane
  - Avoid $\nu_x - 2\nu_y = 0$ and $\nu_x - \nu_y = 0$ resonances
    - Driven by upright sextupole, coupling
    - Crossed slowly because tune varies parallel to them
  - Keep horizontal tune high: small aperture
- Time of flight same at low and high energy
- Attempt to get 500 cell-turns at $a = 1/12$
- Initial guess at pole tip fields same for D and F

# Tune Footprints
# Baseline Configuration

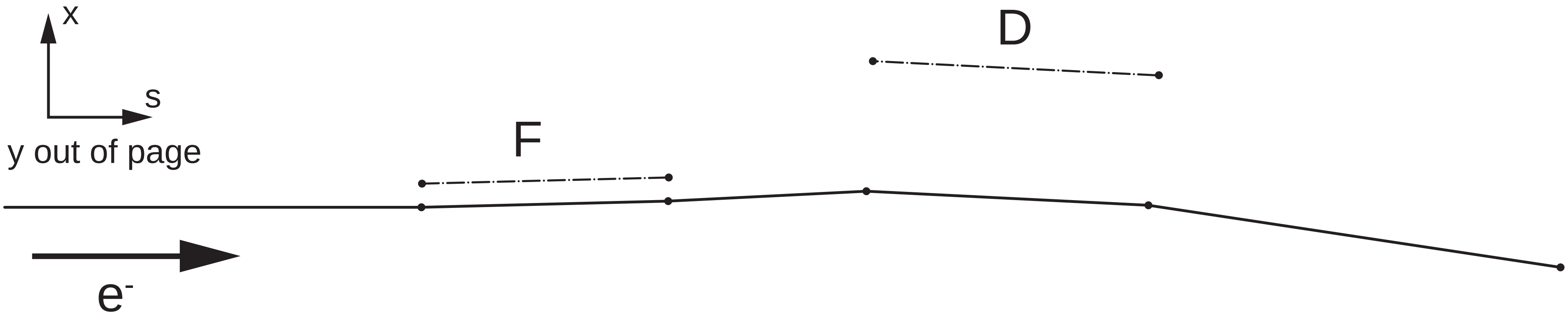


# Lattice Parameters

- Lattice consists of displaced quads
  - Displacement is position of quad center
  - Magnets are rectangular (constant field lines are straight)
- Coordinate system bends by half angle at entrance, half angle at exit
- Assume end fields maintain $\cos(2\theta)$ multipole symmetry (more later!)
- Note: did not seek a harmonic of 1.3 GHz; assumed we could set the frequency

| | |
|---|---|
| Minimum KE | 10 MeV |
| Maximum KE | 20 MeV |
| Cells | 42 |
| Long drift | 210 mm |
| Short drift | 50 mm |
| F length | 59.957 mm |
| F angle | -68.101 mr |
| F displacement | 8.581 mm |
| F gradient | 6.582 T/m |
| D length | 73.088 mm |
| D angle | 217.701 mr |
| D displacement | 32.944 mm |
| D gradient | -4.862 T/m |

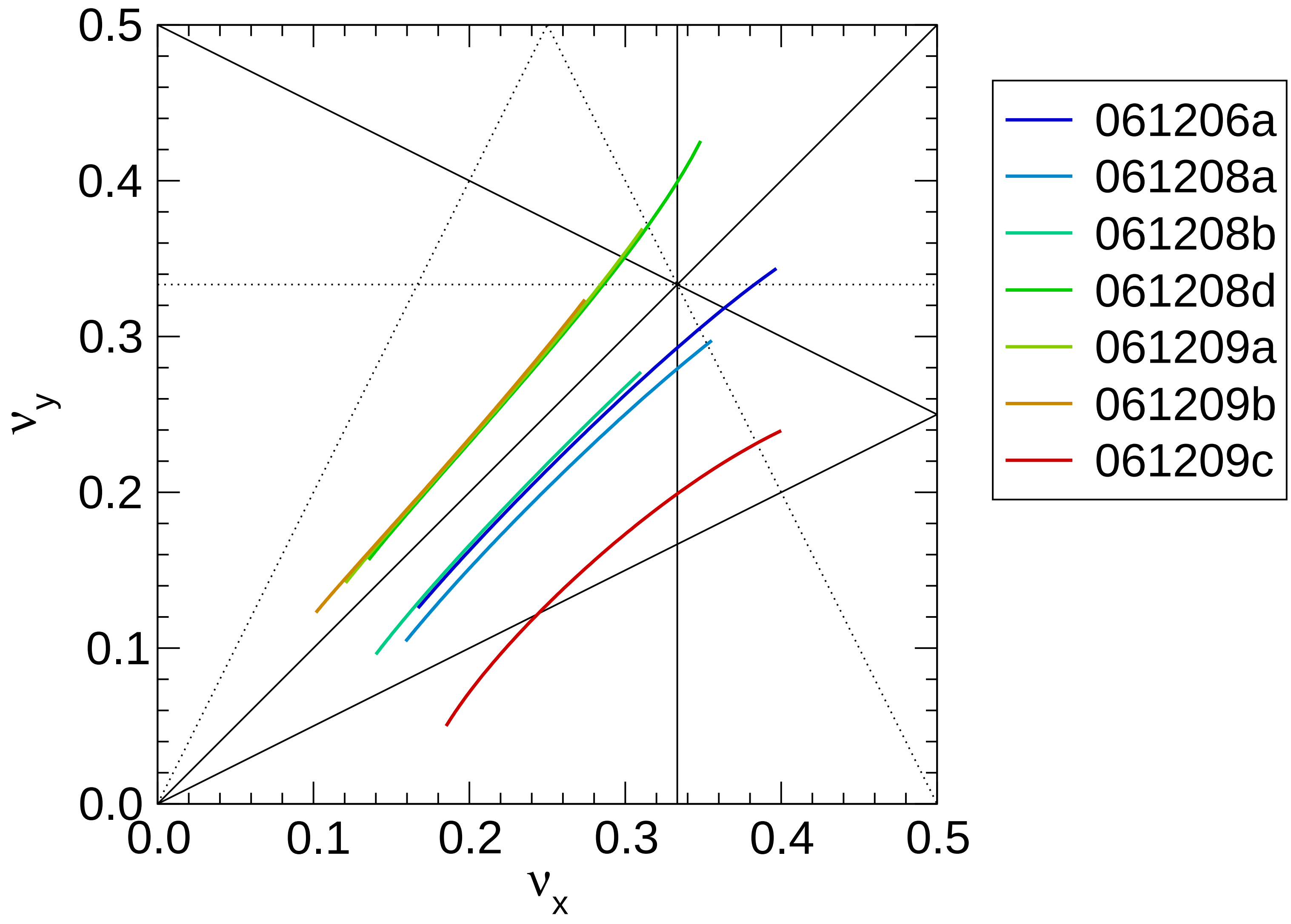
# Lattice Cell Geometry



# Alternate Configurations
# Varying the Tune Footprint

- First, try to vary the tune footprint
- Stay between $\nu_x - \nu_y = 0$ and $\nu_x - 2\nu_y = 0$
  - Cross different numbers of upright third order resonances
- Go above $\nu_x - \nu_y = 0$
  - Cross different numbers of upright third order resonances
- Cross $\nu_x - 2\nu_y = 0$
  - Low energy horizontal tune at 0.4
  - High energy vertical tune at 0.05

# Tune Footprints
## Alternate Configurations



# Modified Lattices

- The beam pipe doesn't move
- The quadrupole gradients can change
- The quadrupoles can be displaced horizontally
- Minimize the increase in the horizontal beam pipe aperture
- Table highlights which parameters are increased by which lattices
- Conclusions
  - Lattices above $\nu_x - \nu_y = 0$ increase aperture too much and aren't as interesting for a real machine: drop them
  - Low-tune lattice between $\nu_x - \nu_y = 0$ and $\nu_x - 2\nu_y = 0$ defined aperture. Keep because it avoids low order resonances (the emergency lattice!).

# Lattice Specs
# Different Tune Profiles

| | 061206a | 061208a | 061208b | 061209c | 061208d | 061209a | 061209b |
|---|---|---|---|---|---|---|---|
| $B_{1D}$ | -4.862 | -4.284 | -3.756 | -3.924 | -5.206 | -4.611 | -3.769 |
| $\Delta x_D$ | 32.944 | 37.976 | 44.852 | 38.794 | 31.181 | 35.944 | 45.673 |
| $x_{\text{min},D}$ | -39.282 | -44.609 | -53.547 | -45.131 | -40.021 | -46.953 | -60.620 |
| $x_{\text{max},D}$ | -18.172 | -22.677 | -28.697 | -24.877 | -16.408 | -20.563 | -29.221 |
| $x_{\text{pmin},D}$ | -6.337 | -6.632 | -8.695 | -6.337 | -8.841 | -11.009 | -14.947 |
| $x_{\text{pmax},D}$ | 14.773 | 15.299 | 16.155 | 13.917 | 14.773 | 15.381 | 16.452 |
| $\Delta y_D$ | 10.977 | 10.142 | 9.779 | 11.659 | 14.453 | 11.173 | 8.175 |
| $B_{1F}$ | 6.582 | 6.021 | 5.187 | 6.473 | 6.076 | 5.384 | 4.401 |
| $\Delta x_F$ | 8.581 | 9.280 | 10.452 | 8.174 | 7.867 | 8.581 | 10.442 |
| $x_{\text{min},F}$ | -25.879 | -26.374 | -30.283 | -24.559 | -28.290 | -31.710 | -38.907 |
| $x_{\text{max},F}$ | 12.206 | 11.438 | 10.334 | 11.255 | 12.957 | 12.205 | 10.345 |
| $x_{\text{pmin},F}$ | -17.298 | -17.094 | -19.831 | -16.385 | -20.424 | -23.128 | -28.465 |
| $x_{\text{pmax},F}$ | 20.786 | 20.718 | 20.786 | 19.429 | 20.824 | 20.786 | 20.786 |
| $\Delta y_F$ | 5.625 | 6.194 | 6.508 | 8.892 | 6.597 | 5.540 | 5.809 |
| $x_{\text{min},C}$ | -14.482 | -14.494 | -17.223 | -13.695 | -17.636 | -20.300 | -25.415 |
| $x_{\text{max},C}$ | 20.025 | 20.025 | 20.180 | 18.701 | 20.084 | 20.124 | 20.225 |
| $\Delta y_C$ | 9.310 | 8.675 | 8.322 | 11.073 | 11.940 | 9.260 | 8.175 |

# Alternate Configurations
# Shifting the Time of Flight Parabola

- Want to explore the effect of the time of flight parabola shape on longitudinal dynamics
- Also, having the same time of flight at minimum and maximum is probably not optimal
- Examine lattices with location of minimum at 14 MeV and 16 MeV kinetic energy
- Conclusions
  - For high tune lattices
    - Required magnet aperture increases are small
    - Small increase in required magnet gradients
  - For low tune lattice, aperture increases are unacceptable
    - Hope we don’t have severe resonance crossing problems: will make it hard to study longitudinal dynamics

# Lattice Specs
# Shifted ToF Parabola

| | (061206a) | | (061209c) | | (061208b) | |
|---|---|---|---|---|---|---|
| | 061210c | 061210d | 061210e | 061210f | 061210g | 061210h |
| $B_{1D}$ | -5.009 | -4.573 | -3.994 | -3.636 | -3.955 | -3.355 |
| $\Delta x_D$ | 27.909 | 42.107 | 35.751 | 50.666 | 35.567 | 62.425 |
| $x_{\text{min},D}$ | -35.616 | -46.369 | -42.242 | -55.355 | -47.394 | -66.155 |
| $x_{\text{max},D}$ | -13.136 | -27.477 | -21.278 | -37.224 | -20.795 | -44.298 |
| $x_{\text{pmin},D}$ | -7.707 | -4.262 | -6.491 | -4.689 | -11.827 | -37.303 |
| $x_{\text{pmax},D}$ | 14.773 | 14.630 | 14.473 | 13.443 | 14.773 | 18.127 |
| $\Delta y_D$ | 11.004 | 10.936 | 11.657 | 11.672 | 9.775 | 9.806 |
| $B_{1F}$ | 6.732 | 6.286 | 6.558 | 6.153 | 5.405 | 4.752 |
| $\Delta x_F$ | 6.216 | 12.505 | 7.378 | 11.804 | 5.536 | 18.574 |
| $x_{\text{min},F}$ | -23.702 | -29.803 | -23.085 | -29.102 | -26.980 | -36.072 |
| $x_{\text{max},F}$ | 15.892 | 5.710 | 13.409 | 4.615 | 15.520 | 1.350 |
| $x_{\text{pmin},F}$ | -17.486 | -17.298 | -15.708 | -17.298 | -21.444 | -17.498 |
| $x_{\text{pmax},F}$ | 22.108 | 18.215 | 20.786 | 16.419 | 21.056 | 19.925 |
| $\Delta y_F$ | 5.566 | 5.688 | 8.886 | 8.912 | 6.435 | 6.558 |
| $x_{\text{min},C}$ | -14.860 | -14.132 | -13.151 | -14.201 | -19.081 | -14.482 |
| $x_{\text{max},C}$ | 21.174 | 17.681 | 19.965 | 15.910 | 20.273 | 19.522 |
| $\Delta y_C$ | 9.392 | 9.152 | 11.096 | 10.982 | 8.424 | 8.126 |

# Alternate Configurations
# Aperture Requirements

- F magnet:
  - Maximum gradient: 6.732 T/m
  - Half-height of 8.912 mm
  - Horizontal: vacuum chamber from -19.831 mm to 22.108 mm
  - Maximum vacuum chamber distance into magnet: 30.283 mm
- D magnet:
  - Maximum gradient: -5.009 T/m
  - Half-height of 11.672 mm
  - Horizontal: vacuum chamber from -8.695 mm to 16.155 mm
  - Maximum vacuum chamber distance into magnet: 55.355 mm
- Cavity
  - Assumed 175 mm length
  - Half-height of 11.096 mm
  - Horizontal: vacuum chamber from -17.223 mm to 21.174 mm

# End Fields and Magnet Symmetry

- We know the field in the magnet body, and we know it outside
- What does the field look like in-between
- Two possibilities:
  - Midplane symmetry: maintain field form in midplane

$$B_y(x, y = 0, s) = f(s)B_{y0}(x)$$

    - ⋆ Appropriate for wide magnets with small vertical aperture
  - Multipole symmetry

$$rB_\phi(r, \phi, s) = f(s)r^m \cos(m\theta) + O(r^{m+2})$$

    - ⋆ Appropriate for magnets constructed with that symmetry: like the EMMA quadrupoles
- Maxwell's equations tell us the rest

# End Fields and Magnet Symmetry
# What's the difference?

- Let's do the dipole case, sharp field change
- Midplane symmetry

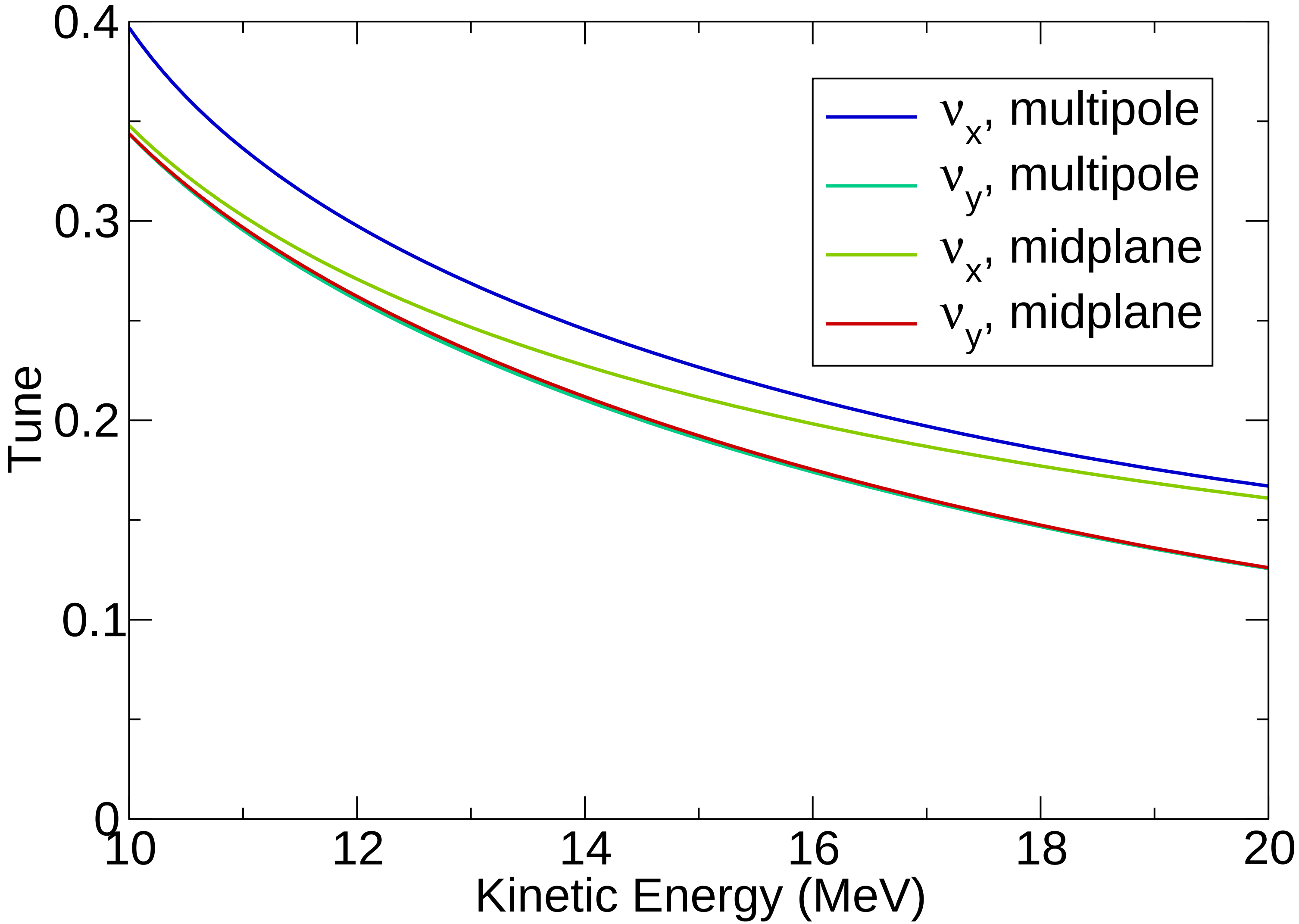
$$B_x = 0 \qquad B_y = B_0\left[1 - \frac{1}{2}y^2\delta'(s)\right] \qquad B_s = B_0 y\delta(s)$$

- Multipole symmetry

$$B_x = -\frac{1}{4}xy\delta'(s) \quad B_y = B_0\left[1 - \frac{1}{8}(x^2+3y^2)\delta'(s)\right] \quad B_s = B_0 y\delta(s)$$

- Note: particle in midplane gets horizontal kick in multipole case
  - Integral is zero, but:
  - Particle gets kick, drifts to different location, gets different reverse kick
- Difference large in EMMA (quads, not dipoles)

# Baseline EMMA Tunes
# Different End Field Symmetries



# More to Do

- Define RF parameters
  - Cavity every third cell, 360 kV/cavity desirable
  - Need to define frequency tuning range (info available, I just haven't computed it. . . )
- Clearly getting some idea of the true end fields is important